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Polar Processes on Mars

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Polar Processes on Mars

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SUMMARY

Included in this publication is a collection of abstracts from the NASA-sponsored workshop "Polar Processes on Mars," which was held at the Sunnyvale Hilton Hotel, Sunnyvale, California, on May 12 and 13, 1988. Support for the workshop came from NASA's Planetary Geology and Geophysics program managed by Dr. Joseph Boyce. The workshop is one of a series of workshops identified by MECA (MECA is an acronym for Mars: Evolution of its Climate and Atmosphere) as being worthy of focused research, but one for which it was not possible to hold during the project's lifetime. Consequently, it was held after the project ended. The MECA project was part of the Mars Data Analysis program.

The workshop consisted of four sessions: The Polar Caps, Dynamics/Atmospheric Processes, Polar Geology, and Future Measurements. To put things into perspective, each of the first three sessions began with a review. All sessions were scheduled to allow ample time for discussion., A brief review of each section is provided.

1 Session I: The Polar Caps

In the first session, workshop participants focused on the behavior of the Martian polar caps. A major unsolved problem concerning the north and south polar caps is why they behave so differently. In the north, carbon dioxide completely sublimes by the beginning of summer exposing an underlying water ice cap which acts as a source for atmospheric water vapor. In the south, no analogous behavior is seen. Instead, CO_2 evidently survives at the south pole all year long. This difference in behavior occurs in spite of the fact that both poles receive the same amount of annual insolation. As Dave Paige pointed out in his review, this behavior is due in part to the higher albedo of the south cap relative to the north cap. But why the south cap is so much brighter than the north cap is a more difficult question to answer.

The preferential occurrence of global dust storms during the time the north cap is forming has been the traditional answer until it was discovered that global dust storms don't necessarily occur each Martian year even though the seasonal surface pressure fluctuations - a measure of cap behavior - repeat almost identically from year to year. One issue that clearly needs attention here is how dust affects the radiative properties of CO_2 frosts. In this regard Steve Warren presented a summary of laboratory data and the results of some modeling studies showing significant differences in the behavior of H_2O and CO_2 ices. For example, to reduce the albedo a given amount, ten times as much dust is required for CO_2 snow compared to H_2O snow.

Further complicating these issues is the possibility that CO_2 does not always survive at the south pole during summer. This possibility was suggested by earth-based telescopic observations of the southern hemisphere during summer which showed much greater amounts of water vapor in the atmosphere than was seen by Viking at the same season. This could be due to the existence of a water ice cap at the south pole that is exposed in some years but not in others. Jakoksy and Haberle suggested a mechanism for such interannual variability that is keyed to the inevitable cold-trapping of water on a perennial CO_2 frost, and the ability of water ice to store energy once exposed. In many respects, the mechanism resembles an instability and therefore requires a perturbation. Variations in the rate of

retreat of the south polar cap during spring, as discussed earlier in the session by Leonard Martin, demonstrate that potential perturbations to the system do exist. The mechanism also depends on the water deposition rate, which according to the modeling calculations of Phil James are quite small at the current epoch (3 to 7 microns per year). However, whether or not such a mechanism actually operates is difficult to determine given the few observations of the south pole during summer. Some additional evidence in favor of a permanent CO_2 reservoir at the south pole was presented later in the session by Dave Paige, but the ultimate determination of the nature of the south polar ices will require further observations.

Two speakers addressed issues regarding the behavior of water ice in the north. Tom Svitek suggested that a redistribution of the Viking Lander 2 winter surface frost by a cold-trapping mechanism could account for the observed Lambertian character of the phase function and relax the requirement for unrealistically large amounts of surface ice, or for identification of the frosts as CO_2 which is not expected to be stable at the observed temperatures. Hugh Kieffer pointed out an interesting paradox. Namely, that light scattering by water ice grains in the residual north polar cap should be dominated by dust since the grains are expected to grow in size during the season. If so, then why isn't the residual cap black?

2 Session II: Dynamics/Atmospheric Processes

Modeling results dominated the Dynamics session which focused on atmospheric processes during northern winter. Jim Pollack led off the session by showing results from the Mars General Circulation Model (GCM) on the nature of CO_2 condensation in the atmosphere. "Polar Hoods" have long been observed in the north polar regions during winter and are believed to be composed of both water and CO_2 clouds. The GCM results suggest that CO_2 condensation occurs commonly in the atmosphere as well as at the surface. Atmospheric heat transport by both the baroclinic eddies and the mass flow inhibit condensation near the edge of the cap, but are less effective near the pole where most of the

CO_2 condensation is predicted to occur. Suspended dust particles were found to significantly increase atmospheric condensation, thus suggesting an efficient scavenging mechanism.

Much of this session delt with the issue of how and when dust and water are transported to the poles since the layered deposits there are believed to have formed by atmospheric sedimentation processes. Jeff Barnes presented some transport results based on numerical simulations with simplified but realistic models which showed that during a polar warming substantial quantities of dust and water can reach and settle out upon the pole. Although his model assumes a planetary wave mechanism is driving the polar warming, Jeff pointed out that similar results should hold given other scenarios.

Continued research into the cause of the polar warming, which was clearly related to the second global dust storm of 1977, should further our understanding of this important phenomena. To that end Jeff Hollingsworth presented some preliminary results from his spherical primitive equation wave-mean flow model (single wave) which allows for meridional as well as vertical wave propagation. Meridional propagation could be potentially important since it would allow waves excited at lower latitudes where topographic relief, and hence wave-forcing mechanisms, to be channeled into the polar regions.

Global dust storms, however, do not occur every Martian year. Is dust and water transported into the polar regions at these times? Haberle *et al.* have been investigating this question with a 3D global spectral model by simulating the winter circulation assuming clear atmospheric conditions. Based on certain dynamical indicators, such as the residual circulation and EP fluxes, the the non-dust-storm Martian circulation during winter appears to be much less able to transport material to the poles themselves. They point out, however, that a full transport calculation is needed to better assess this preliminary result.

In the final paper of the session, Jim Murphy addressed the issue of how dust is removed from the atmosphere. Using Viking lander data to constrain a 1D aerosol model that accounts for most of the relevant physics (e.g., coagulation, diffusion, and particle shape) he found that the observed decline in solar optical depth at the lander 1 site during the first global dust storm of 1977 can be reasonably well simulated if the particles are plate-like in shape; spherical particles generally fell out too quickly. However, in none of the simulations

did the particle size distribution remain relatively constant as appears to be the case from various analyses of Mariner 9 data on the 1971 storm.

3 Session III: Polar Geology

The Polar Geology session focused on the the age and composition of the south polar layered deposits, the nature and source of the dune material surrounding the residual north polar cap, and the mass balance of the north cap itself. Following Steve Squyres review, Ken Herkenoff presented an analysis of Viking color mosaics of the south polar layered deposits which show them to be darker and less red than the dust that mantles much of the south polar region suggesting compositional differences between the two units. The age of the deposits themselves was addressed in a talk given by Ralph Kahn. The discovery of 15 craters of impact origin on the south polar layered terrains suggests that the surface is older than previously thought. The implication is that the period of layer formation is longer, or the deposition mechanism ceased operating much earlier.

An important geologic feature of the north polar region is the dune fields which surround the residual polar ice cap. Dunes require sand sized particles for formation but the source of these particles has been uncertain. The traditional view is that they are brought in by atmospheric motions as dust/ice particles. Peter Thomas found, however, that their color and morphologic association suggest they form from the erosion products of the layered deposits. Furthermore, because they are similar to sand materials found in other parts of the planet, no exotic polar processes are required to form them. An example of an exotic polar process was given by Steve Saunders who suggested that if the polar layered deposits contain fine smectite clays and water, which they may, then a low density residue, one much more readily movable by saltation than common mineral grains, might form as the material sublimes. Evidently, laboratory experiments demonstrate this possibility.

In the final paper of the session, Steve Clifford presented arguments for the existence of meltwater at the base of the polar deposits. He began by pointing out that the absence of craters greater than 300 m in diameter requires a net deposition rate that would have

produced much thicker deposits than we currently see. If, however, the deposits have reached the thickness required for basal melting, then recycling via subsurface aquifers would maintain a constant thickness despite the net deposition.

4 Session IV: Future Measurements

In the last session of the workshop, researchers involved in Earth's polar sciences described their work and how it might relate to Mars. Dan Boice discussed the possibility of polyoxymethylene (POM) existing at the polar caps of Mars and how it might be useful as a tracer of Martian climate. Similarly, Ed Zeller showed how past levels of solar activity might be recorded in the Martian polar ices. The potential amount of information contained in a well selected core was demonstrated in an invited talk by Dominique Raynaud who presented results of analysis of air bubbles trapped in the Antarctic ice cores. Amazingly, it even appears possible to determine surface pressure at past epochs, a measurement particularly tantalizing for Mars. Workshop participants were then treated to Bruce Koci's slide show on the field use of a composite Auger for extracting cores.

In the final two talks of the session, Steve Squyres and Andy Ingersoll discussed the measurements that Mars Observer will be making that are relevant to Polar Processes: the Gamma-Ray Spectrometer for its ability to determine surface composition, and the Pressure-Modulated Infrared Radiometer for its ability to retrieve atmospheric temperature profiles which can be used with a suitable model to derive winds and, hence, transport.

PROGRAM

MECA WORKSHOP "POLAR PROCESSES ON MARS"
Sunnyvale Hilton Hotel May 12 - 13, 1988

Wednesday Evening May 11, 1988

7:30 - 10:00	Registration and welcome reception

Thursday Morning May 12, 1988

8:00 - 9:00	Registration (Continued)/Coffee and pasteries
9:00 - 9:10	Welcome and Overview - Bob Haberle

SESSION I: THE MARTIAN POLAR CAPS (Bruce Jakosky, Chair)

9:10 - 9:50	Dave Paige. **The Martian Polar Caps: A Review**
9:50 - 10:10	James, P.B. **Water trapping by the Martian polar caps.**
10:10 - 10:30	Svitek, T., and B. Murray. **Properties and stability of Viking lander 2 winter frost.**
10:30 - 10:50	Break
10:50 - 11:10	Kieffer, H.H. **How dirty is Mars' polar cap, and why isn't it black?**
11:10 - 11:30	Martin, L.J., and P.B. James. **Interannual variations in the seasonal recessions of the Martian polar caps.**
11:30 - 11:50	Jakosky, B.M., and R.M. Haberle. **Interannual instability of the south polar cap on Mars.**
11:50 - 1:00	Lunch
1:00 - 1:20	Warren, S.G. **Optical constants of Carbon Dioxide ice.**

Thursday Afternoon May 12, 1988

SESSSION I CONTINUED

1:20 - 1:40	Paige, D., Herkenoff, K.E., and B.C. Murray. **Mariner 9 observations of the south polar cap of Mars: Evidence for a residual CO_2 frost.**
1:40 - 2:00	Discussion

SESSION II: DYNAMICS/ATMOSPHERIC PROCESSES (Dave Paige, Chair)

2:00 - 2:40	Bob Haberle. **Dynamics/Atmospheric Processes: A Review.**
2:40 - 3:00	Pollack J.B., Haberle, R.M., Schaeffer, J., and H. Lee. **Simulations of the general circulation of the Martian atmosphere. I. Polar processes.**
3:00 - 3:20	**Break**
3 :20 - 3:40	Haberle, R.M., Young, R.E., and H. Houben. **Perpetual winter simulations of the Martian atmospheric circulation using a 3D global spectral model: Implications for the poleward transport of water.**
3:40 - 4:00	Barnes, J.R. **On the transport of dust and water to high northern latitudes in Martian dust storms.**
4:00 - 4:20	Hollingsworth, J.L., and J.R. Barnes. **Numerical modeling of planetary wave-mean flow interaction in the Mars atmosphere: Applications to a sudden polar warming.**
4:20 - 4:40	Murphy, J., Toon, O.B., and J.B. Pollack. **Dust particle fallout during global dust storms: 1D simulations.**
4:40 - 5:00	Discussion

Thursday Evening May 12, 1988

6:00 - 7:00	Reception/Cash Bar

Friday Morning May 13, 1988

SESSION III: POLAR GEOLOGY (Bob Haberle, Chair)

9:00 - 9:40	Steve Squyres. **Polar Geology: A Review.**
9:40 - 10:00	Herkenoff, K.E., Wu, S.S.C., Soderblom, L.A., and B.C. Murray. **Quantitative properties of the south polar layered deposits on Mars.**
10:00 - 10:20	Plaut, J., Kahn, R., Guiness, E., and R. Arvidsion. **Accumulation of sedimentary debris in the south polar region of Mars, and implications for climate history.**
10:20 - 10:40	Thomas, P.C. **Mars: Dune sand sources in the north polar layered deposits.**
10:40 - 11:00	**Break**
11:00 - 11:20	Saunders, R., Storrs, A., Blewett, D., Fanale, F., and J. Stephens. **Mars: North Polar Dunes: Possible formation from low-density polar sublimate residues.**
11:20 - 11:40	Clifford, S.M. **Basal melting and the Martian polar mass balance.**
11:40 - 12:00	Discussion
12:00 - 1:30	Lunch

Friday Afternoon May 13, 1988

SESSION IV: FUTURE MEASUREMENTS (Steve Squyres, Chair)

1:30 - 1:50	Boice, D.C., and W. F. Huebner. **Polyoxymethylene at the polar caps of Mars?**
1:50 - 2:10	Dreschhoff, G., and E.J. Zeller. **Martian polar cap analytical system: Objectives and design.**
2:10 - 2:30	Raynaud,D. **Environmental and climate records for Antarctic ice cores.**
2:30 - 2:50	Koci, B. **Field use of a composite coring auger in polar regions.**
2:50 - 3:10	**Break**
3:10 - 3:30	Squyres, S. **Investigation of H2O and CO2 in the Martian polar regions via gamma-ray spectroscopy.**
3:30 - 3:50	Ingersoll, A.P. **A strategy for the climatological science objectives of the Mars Observer Mission.**
3:50 - 5:00	General Discussion
5:00	Adjourn

SESSION I: THE MARTIAN POLAR CAPS

WATER TRAPPING BY THE MARTIAN POLAR CAPS; P.B. James. Physics Dept., U.Missouri-St. Louis

The CO_2 polar cap in the southern hemisphere of Mars survived through the summer season observed by Viking Orbiter 2 in defiance of most predictions (1,2). A recent analysis of Mariner 9 observations establishes that the 1972 residual cap also contained CO_2 (3). The growth of the residual cap during the interval between the Viking observations and 1972 Mariner 9 observations seems to suggest a net deposition of CO_2 during the intervening period (1), although there are no observations which unambiguously establish the composition of incremental ice deposits within the residual cap. Both visual and IRTM observations (4) indicate that the residual south polar cap has a high albedo relative to other ice deposits on the planet; the high albedo accounts for its ability to survive the large insolation during southern summer. Observations therefore suggest that residual CO_2 was present during at least most of the 1970's.

MAWD observations revealed a significant gradient in the average annual concentration of water vapor (5) which would result in a net transfer of water from the northern hemisphere to the southern hemisphere (6) unless it was maintained by some physical process. One would then expect that the CO_2 residual south polar cap would act as a cold trap for some of the vapor transported to the south and that water ice would gradually build up as a contaminant in the dry ice cap. Even if some process maintains the gradient in vapor concentration by "pumping" vapor in the opposite direction, one would expect some water to be trapped in the residual cap, though perhaps at a reduced rate (7). The amount of contamination is important because a water ice component may interfere with processes which maintain the high albedo of the south cap in spite of the presence of dust (8).

The one dimensional water transport model reported in (7) has been used to study the question of the direction of water transport on Mars. Inasmuch as studies of the microphysics of martian clouds suggest that water ice clouds on Mars rarely, if ever, precipitate (9), the assumption that ice formed when the atmosphere becomes saturated is immediately precipitated has been abandoned; the model has been augmented by the inclusion of clouds of ice particles which are transported by the prevailing circulation in the same way as the water vapor. Ice precipitates only when the minimum diurnal temperature reaches the CO_2 condensation point; the model is therefore consistent with the concept that CO_2 clouds form during the polar night and that at least some of the surface cap forms by precipitation.

Simulations with no residual CO_2 cap in the south result in a steady state distribution of water which includes a residual north polar H_2O ice cap, no residual south polar cap, a vapor distribution which is similar to that observed, and a distribution of clouds which resembles observations of polar hoods and circumpolar clouds. Simulations which include a CO_2 residual cap in the south produce similar vapor and cloud distributions to those without the CO_2 cap as long as the residual water cap remains in the north; the cold trap in the south inevitably drains the north polar residual water cap, however, and vapor and cloud distributions then change greatly.

During the transition period, when the north residual cap is losing water to the CO_2 cap in the south, the rate of transfer is between 60μm and 140μm per Martian year for reasonable values of the transport parameters. These models are not very reliable for calculations involving the residual cap, however, because the physical size of the cap is small relative to their spatial resolution. In this case, the surface area of both residual caps is 2% of the area of the planet, ie the size of the residual south cap is overestimated by a factor of 20. Inasmuch as the gradient of water vapor density vanishes as the poles are approached, the amount of water deposited on the south cap should mainly depend upon its surface area. This therefore suggests that the actual transfer should be between 3μm and 7μm per year. This result would suggest that the transfer rate is not large enough at this time to transfer more than about a few meters during an oscillation in the planet's orbital parameters.

(1) James, P.B., G. Briggs, J. Barnes, and A. Spruck (1979) *J. Geophys. Res.* **84**, 2889-2922.

(2) Kieffer, H.H. (1979) *J. Geophys. Res.* **84**, 8263-8288.

(3) Paige, D.A., K.E. Herkenhoff, and B.C. Murray (1988). *Mariner 9 Observations of the South Polar Cap of Mars: Evidence for Residual CO_2 Frost* , Mars Polar Processes Workshop, this volume.

(4) Paige, David A. (1985) *The Annual Heat Balance of the Martian Polar Caps from Viking Observations*, California Institute of Technology thesis.

(5) Jakosky, B.M. and C.B. Farmer (1982) *J. Geophys. Res.* **87**, 2999-3019.

(6) Jakosky, B.M. (1983) *Icarus* 55, 1-18 and 19-39.

(7) James, P.B. (1985) *Icarus* **64**, 249-264.

(8) Kieffer, H.H. and D.A. Paige (1986) *Symposium on Mars: Evolution of Its Climate and Atmosphere*, LPI Contribution 599, 55-56.

(9) Rossow, W. B. (1978) *Icarus* 36, 1-50.

Properties and Stability of Viking Lander 2 Winter Frost. T. Svitek and B. Murray, Department of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125.

Phenomenon of the Viking Lander 2 winter frost is both a consequence and a clue to:
(1) the volatile transport processes operating on Mars,
(2) the soil/atmosphere interaction, and
(3) the local micrometeorology.

In this study we are focusing on two specific lines of investigation to better delineate this phenomenon. The Viking Lander 2 observations of the winter frost (*Guiness et al 1979, Jones et al 1979*) are particularly important as our only in-situ observation of the seasonal polar cap. However, there still exists controversy over the composition (*Hart and Jakosky 1986*). On the one hand, CO_2 is assumed not to be stable under the estimated thermodynamical regime. On the other hand, not enough H_2O is available to explain the observed optical properties (*Wall 1981*). The observed phase function has a Lambertian character which requires a layer of at least 100 precipitable micrometers. Most of the frost disappears around $L_S = 360$, significantly before there is a rise in the water vapor column abundance observed in the atmosphere ($L_S > 30$).

We have proposed a mechanism which could resolve this problem by invoking cold trapping in the soil during the latter phase of the frost presence. This was motivated by the bimodal character of the aerial coverage of the frost as a function of season. During the second phase, the frost accumulates at thermodynamically favorable locations because its removal by atmospheric circulation is limited. This effect leads to a much thicker layer than otherwise would be expected, and thus satisfies the phase function observations.

The contribution of this presentation at the workshop consists of the following data:

1) Phase function measurements of the frost on a much larger sample than attempted before, and also as a function of L_S. The preliminary results indicate than the frost does not have the Lambertian phase function earlier in the season (which would imply a very thin layer).

2) Color changes of the frost, again as a function of L_S. There are hints that the frost was much whiter later in the season than when it formed.

3) Frost stability calculation. We have tried to critically determine the surface temperature using the local values for albedo and atmospheric optical depth. Also, Viking meteorology results (wind and temperature) were used to estimate the effect of horizontal heat transport by the atmosphere. This was correlated with orbital IRTM and MAWD observations above the Viking Lander 2 site. Finally, the resulting surface temperatures were compared with the Lander footpad temperature measurements.

References: 1) Guiness, E. A., et al, 1979. Color changes at the Viking Lander sites over the course of a Mars year, JGR, **84**, 8355-8364. 2) Hart, H. M., and B. M. Jakosky, 1986. Composition and stability of the condensate observed at the Viking Lander 2 site on Mars. Icarus, **66**, 134-142. 3) Jones, K. L., et al, 1979. One Mars year: Viking Lander imaging investigation. Science, **204**, 799-806. 4) Wall, S. D., 1981. Analysis of condensate formed at the Viking Lander 2 site - the first winter. Icarus, **47**, 173-183.

HOW DIRTY IS MARS' NORTH POLAR CAP, AND WHY ISN'T IT BLACK?

Hugh H. Kieffer, U. S. Geological Survey, Flagstaff, AZ 86001

Global studies of Mars seem to indicate conclusively that the seasonal polar caps are CO_2, that the residual north polar cap is H_2O, and that the north polar region is an annual net source of water vapor. More detailed observations show the late-summer north polar cap to be composed of bright icy areas with interspersed darker layered terrain (lanes), presumably composed of dust. However, simple models suggest that old dirty ice should be nearly as dark as, or darker than, the layered terrain.

Well-established observations are that in mid-summer, (1) the bright north polar material has an albedo near 0.41 and a temperature near 210 K; (2) the dark material has an albedo near 0.24 and a temperature near 235 [1]; (3) the column water-vapor abundance in the north polar region is 30-100 precipitable microns; (4) the atmosphere over the cap is virtually saturated with water vapor; and (5) water-vapor abundance decreases away from the edge of the polar cap, definitely toward the equator, and probably toward the pole as well [2,3,4].

Viking Lander measurements indicate that the average visible opacity of the Martian atmosphere is on the order of unity and that the average annual global dust content of the atmosphere, by mass, is comparable to the average annual global water-vapor content [5]. Although there is considerable uncertainty as to just how and when water vapor and dust are carried into the seasonal polar cap, the average global values indicate deposition of a few milligrams/cm^2 of each in the seasonal polar cap, corresponding to a visual opacity in the deposit due to dust alone of approximately 10.

The dust and H_2O must initially be fine grained because they are transported into the polar region in suspension, probably as nuclei of CO_2 snow grains. The H_2O grain size cannot change significantly until the seasonal CO_2 is gone, because the metamorphism rate of H_2O at 145 K is negligible [6]. Thus, the expected composition of material residual from the current seasonal cycle is a mix of fine dust and H_2O in comparable abundance. In fine-grained ice-dust mixtures, even a 0.001 mass fraction of dust is sufficient to lower the visual reflectance to approximately 0.4 [7]. Metamorphism during the summertime warming of the residual cap will further lower the albedo by decreasing the surface area of H_2O grains while not affecting the surface area or spatial dispersion of the dust grains.

If the residual north polar cap is undergoing net annual sublimation, late summer observations should be of old dirty ice. Gradual metamorphism over many annual thermal cycles is calculated to result in H_2O grain sizes on the order of 100 microns. Ice of this granularity containing 50% fine dust has a reflectivity similar to that of dust alone.

The brightness of the ice areas conflicts with what would be expected for a residual cap deposited by an annual cycle similar to that observed by the Viking mission and aged for thousands of years. A possible explanation for the brightness of the residual cap is that the bright areas are accumulating frost in the late summer, while the dark areas are losing water vapor. This is not unreasonable, because the atmosphere is virtually saturated, and the bright areas are about 25 K cooler than the dark areas and are probably at a temperature below the atmospheric frost point. This accumulation could be "clean," in that atmospheric dust need not be carried into the deposit (as occurs for CO_2 frost), and there is no obvious constraint on the grain size of H_2O hoar frost.

Another possible explanation is that dust is a minor component of the residual H_2O cap, which implies that the material now at the cap surface formed in an atmosphere far cleaner than the present one.

The high thermal inertia observed for the residual north polar cap [8] is near that expected for bulk water ice and is suggestive of older, coarse-grained ice. The amount of water and dust deposited in one season is too small to influence the thermal inertia significantly, even if the material remains extremely fine grained and of low thermal conductivity. Hence, the last year's H_2O-dust deposit could significantly influence the brightness of the cap, but not its thermal inertia.

If we are observing an annual process, the dominant source of any H_2O accumulating on the residual caps in summertime must be the H_2O that was incorporated in the seasonal CO_2 cap and that was residual on the dirt surface when the CO_2 disappeared. By the end of the summer, the upper few centimeters of the dark lanes are probably desiccated down to a level at which diffusion inhibits the net removal of water [4].

The dichotomy of terrains in the north polar region may thus be stronger than generally realized. In the current climate, the bright areas may have net volatile accumulation while the dark lanes are depleted of perennial volatiles, at least near the surface. The net polar source of water implies that the bright areas are shrinking laterally. "Old" volatiles may be inaccessible to sampling of the north polar region; they may have either retreated below the surface of the dark terrains or been buried beneath young water ice in the bright areas.

The composition and annual budget of the residual caps and the local volatile transport suggested here should be well addressed by the complement of nadir-looking instruments on the Mars Observer spacecraft.

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[2] Farmer, C. B., D. W. Davies, and D. D. LaPorte (1976) Science 194, pp. 1339-1341.

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INTERANNUAL VARIATIONS IN THE SEASONAL RECESSIONS OF THE MARTIAN POLAR CAPS; L.J. Martin, Planetary Research Center, Lowell Observatory, and P.B. James, Physics Dept., U.Missouri-St.Louis

The periodic changes in the appearance of the Martian polar caps in response to seasonal insolation variations have been studied since their cause was deduced by Wm. Herschel (1). Slipher (2) examined telescopic observations of the south polar cap from 1798 to 1956 and concluded that there was no evidence for variations between recessions. The historical support for such variations is much better for the north polar cap (3,4), although these observations are less reliable because they are obtained during aphelic oppositions and are more subject to cloud confusion. Spacecraft observations revealed changes in the residual south polar cap (5) and suggested some modest differences between successive north cap regressions (6).

We have now examined data from all oppositions monitored by the International Planetary Patrol between 1969 and 1982 (7) in addition to subsequent observations in 1984 and 1986 and have reanalyzed some of the earlier Lowell Observatory data (8) in order to determine regression behaviors for both polar caps during relevant oppositions of the last 30 years. The data highlight the rather different qualitative behaviors of the two polar caps during their seasonal recessions. The regression curve for the south cap is characterized by a relatively constant slope; the major distinctive feature of the south cap regression is the longitudinal asymmetry which results in a fairly large displacement of the cap from the geographic pole by southern summer solstice and a somewhat accelerated regression slope during mid-spring. The major feature of the north cap regression curve is a plateau or standstill at about 65° Latitude during mid-spring, from roughly $L_s=20°$ to $L_s=50°$. Circumpolar condensate clouds are very prevalent during the late winter and early spring in the north and reappear during the "post plateau" recession; there is little cloud activity observed during corresponding seasons in the south.

The data from the south cap recessions of 1956, 1971, 1973, 1977 (Viking), and 1986 establish that there is significant year to year variation in the regression of the south cap. The 1977 and 1971 regressions are very similar and near mean, at least until the start of the large 1971 dust storm at $L_s=260°$; the data do not, therefore, particularly support the hypothesis that the differences between 1971 and 1977 residual caps reflected a retarded 1977 regression. Interannual differences between north cap recessions reported by Iwasaki et al. (9) were not confirmed because the Planetary Patrol data were taken only during the best portions of the various oppositions and do not, therefore, have sufficient overlap to reveal such effects. The regression data by themselves do not suggest the nature of the variations (eg frost redistribution or variable condensation) or a particular mechanism (eg radiative effects of dust, solar cycle, or variable advection) responsible. Attempts to correlate with the pattern of global and hemispheric duststorms, which is quite variable, have not revealed a consistent pattern, partly because of incomplete data on the storms (10).

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INTERANNUAL INSTABILITY OF THE SOUTH POLAR CAP ON MARS

Bruce M. Jakosky and Robert M. Haberle

Observations of the abundance of water vapor in the martian atmosphere made in 1969 showed large amounts of water during the southern-hemisphere summer season. These abundances were similar to those seen during the northern-hemisphere summer season, and suggested that both polar caps lost their seasonal carbon-dioxide frost during the summer, exposing an underlying water-ice deposit which could then heat up and supply water to the atmosphere. Observations from the Viking spacecraft during 1976-1979 indicated that, while the north-polar cap did lose its CO_2 frost cover during summer, the south-polar cap did not. Although the water vapor observations are not conclusive proof of an exposed south-polar water-ice cap in 1969, they have led us to further investigate the annual and interannual stability of the south-polar cap.

We have constructed a simple energy-balance model of the two polar caps, incorporating solar insolation, thermal emission from the surface and from the atmosphere to the surface, conduction of heat into the subsurface, the condensation and sublimation of carbon-dioxide frost at the surface, and an accurate orbit around the sun. The model was intentionally kept simple in order to isolate the suspected role of subsurface energy conduction. Processes not incorporated include a season-dependent frost albedo, atmosphere dust component, or atmospheric pressure; these are thought to produce second-order changes in our results. For the surface thermal-emission brightness temperature assumed in the model, a CO_2-frost albedo of 0.74 was required to allow frost to remain all year on the south cap. Differences between this number and the albedo observations compiled by Paige and Ingersoll (1) result because our albedo is that of the surface while theirs is the planetary albedo including atmospheric effects; a small amount of atmospheric dust will bring the numbers into agreement.

Using this same value for the CO_2 frost albedo, the solution was also stable with the surface in a configuration in which the CO_2 frost completely disappeared by about midsummer, exposing the underlying surface. This situation occurred when the subsurface started out warm and the underlying surface had an albedo less than that of the CO_2 frost. In this case, energy conducted into the subsurface during summer was conducted out again during winter, causing less CO_2 frost to condense and resulting in its complete removal by the following midsummer. Thus, the current state of the polar cap depends on its previous state: If it starts out cold, it will be capable of retaining a CO_2 frost deposit year round. It it starts out warm or if all of the CO_2 frost is removed one year to expose the underlying material, then it will be be in a stable configuration at the current epoch, with the underlying cap being exposed at midsummer.

The presence of a water-ice cap underlying the carbon-dioxide frost at the south pole is guaranteed because the latter will act as a cold trap for the former. If water is deposited onto the south cap at the rate discussed by Haberle and Jakosky (2), then there must be several meters of water ice beneath a CO_2 frost layer which almost disappears each year. In this case, subtle effects can cause the cap to jump from one stable state to the other.

MARS POLAR CAPS

B. M. Jakosky and R. M. Haberle

An additional frost heating during spring, due for example to an additional atmospheric dust load, will cause the CO_2 frost to disappear at a time when the sunlight is still sufficient to heat up the surface. The energy stored in the subsurface as the cap heats up, even if only a few degrees and for a few days, will resurface the next year. For an albedo of the underlying material lower than that of the CO_2 frost, this will trigger an unstable jump to the alternate stability state, with the cap exposed at midsummer.

A jump back from uncovered to covered requires an increase in the water-ice albedo to a value greater than the CO_2-frost albedo. This could result, for instant, from the transport one year of an increased amount of water ice but not of dust to the south-polar region. This water ice could deposit as a fine-grained frost with high albedo. Dust transported to the pole in subsequent years could then lower the albedo to allow a jump back to the uncovered state.

In summary, the south-polar cap has two equally stable states, one in which it is covered by carbon-dioxide frost all year, and one in which the CO_2 frost disappears in midsummer: its current state is determined by its state the previous year. Additionally, subtle atmospheric effects involving the transport of water vapor and dust to the cap can cause it to jump from one stable state to the other. As an aside, the hypothesis presented here is mutually exclusive with the idea of the south-polar CO_2 cap acting to buffer the atmospheric pressure.

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MARINER 9 OBSERVATIONS OF THE SOUTH POLAR CAP OF MARS: EVIDENCE FOR RESIDUAL CO_2 FROST; D. A. Paige (UCLA), K. E. Herkenhoff and B. C. Murray (Caltech)

Determining the composition of the martian residual polar caps is fundamental to our understanding of the Mars climate system. In this study, we analyze an extensive set of observations of the Martian south polar cap obtained by Mariner 9 during the summer season of 1971 and 1972. These data include wide angle and high-resolution narrow angle TV images and Infrared Interferometer Spectrometer (IRIS) spectra. The results give conclusive evidence for the presence of surface CO_2 frost at the south residual cap throughout the summer season.

In 1966, Leighton and Murray proposed that the observed partial pressure of CO_2 at the surface of Mars was the consequence of permanent solid CO_2 deposits at the poles (1). The Viking observations of 1976 and 1977 showed that the north residual cap was composed of water ice (2), whereas the south residual cap appeared to contain residual CO_2 frost at the end of the summer season (3). There are two pieces of evidence that suggest that the south polar cap behavior observed by Viking may not have been typical. Comparisons between Viking orbiter images of the retreating south seasonal polar cap and those obtained three Mars years earlier by Mariner 9 show that the Viking cap receded to the same point approximately 17 days later than the Mariner 9 cap (4). The "residual" cap observed at the end of the summer season by Viking had greater frost coverage than the residual cap observed by Mariner 9. Also, telescopic observations of mars water vapor abundances show that the atmosphere of Mars may have contained significantly greater abundances of water vapor during the late summer season of 1969 than were observed during the Viking year (5). Both these observations have been interpreted to suggest that the CO_2 frost at the south residual cap is completely sublimated during certain years. If true, they would imply that the bulk of the bright deposits at the south residual cap are water ice, and that a significant permanent martian CO_2 frost deposit does not presently exist.

Our analysis of the Mariner 9 observations focuses on determining whether surface CO_2 frost was present at the south residual cap. The analysis employs both the IRIS spectrometer data and the wide angle camera system data. When used together, they provide strong constraints on the surface thermal emission from the south residual cap. Each IRIS south polar cap spectra is analyzed with a three-component surface emission model, with five independent input parameters: T_{CO_2}, the temperature of CO_2 frost, F_{CO_2}, the fraction of the IRIS field of view containing CO_2 frost, T_{H_2O}, the average temperature of water ice, F_{H_2O}, the fraction of the IRIS field of view containing water ice and T_{ground}, the average temperature of dark bare ground within the IRIS field of view. F_{ground}, the fractional bare ground coverage for each IRIS spectra, is taken from simultaneously acquired wide angle images. The five independent input parameters are varied widely in all possible combinations. Those combinations of input parameters that yield calculated brightness temperatures at atmospheric window wavelengths of $\lambda = 12\mu$ and $\lambda = 34\mu$ that do not agree with the IRIS measurements at these wavelengths are discarded. The remaining combinations of input parameters are then considered to be consistent with the available observations and their uncertainties. The analysis was performed for south polar cap spectra obtained on orbits 28 ($L_s = 301$), 58 ($L_s = 310$), 116 ($L_s = 326$) and 188

($L_s = 345$). In each case, the model results were consistent with the observations only if they included the presence of CO_2 frost within the IRIS field of view at temperatures of 150K or below.

The results of this study raise questions about the nature and stability the martian south residual cap deposits. High resolution Mariner 9 narrow angle camera images show that the frost coverage within the south residual cap was highly non-uniform at all observable spatial scales (6). The broken-up appearance of the south residual cap does not immediately suggest the presence of a significant solid CO_2 or water ice deposit. Yet, it would be a remarkable coincidence if we happened to live in a time in which there is exactly enough CO_2 in the Mars cap-atmosphere system to just barely support a permanent CO_2 deposit.

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ABSTRACT for MECA Workshop "Polar Processes on Mars", May 1988.

OPTICAL CONSTANTS OF CARBON DIOXIDE ICE

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Understanding the reflection, transmission, absorption, and emission of radiation by materials containing CO_2-ice requires knowledge of the optical constants of pure clear solid CO_2. Laboratory measurements of the absorption coefficient and refractive index are reviewed for all parts of the electromagnetic spectrum from the ultraviolet to the microwave, with emphasis on values for temperatures above 77 K. The available measurements in some cases require reinterpretation. A compilation of the spectral absorption coefficient k_{abs} is made for 52-nm to 160-μm wavelength (with some gaps because of lack of data), and the complex refractive index is then computed by Kramers-Kronig analysis. The uncertainty in imaginary refractive index varies greatly with wavelength. The real part of the refractive index is close to 1.4 for all parts of the spectrum except near strong absorption bands, and is accurate to $\pm$ 0.05 outside those bands. No measurements of absorption are available for 180-330-nm, 1.0-2.5-μm and 25-μm-25-mm wavelength, except in the strong narrow absorption lines. A remeasurement of k_{abs} is also needed for parts of the infrared spectrum between 2.5 and 25 μm because of experimental error in the available measurements.

This compilation will be used to compute spectral albedo and emissivity of carbon-dioxide frost.

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SESSION II: DYNAMICS/ATMOSPHERIC PROCESSES

Simulations of the General Circulation of the Martian Atmosphere.
I. Polar Processes

James B. Pollack and Robert Haberle
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Sterling Software

We have conducted numerical simulations of the general circulation of the Martian atmosphere with a 3 dimensional model based on the primitive equations of meteorology. Line by line calculations were carried out to obtain an accurate specification of the absorption properties of carbon dioxide gas at solar and thermal wavelengths and single and multiple scattering calculations were performed to derive an accurate specification of the interactions of suspended dust with solar and thermal radiation. A bulk parameterization scheme was used to evaluate the exchange of heat and momentum between the surface and atmosphere. The model incorporated Mars consortium information on the spatially varying topography, thermal inertia, and albedo of the surface.

A large number (16) of numerical experiments were carried out for spatially and temporally constant dust loading (for a given experiment) to determine the steady state response of the atmosphere to different choices of dust optical depth (0-5) and seasonal date (6 dates spaced about 60° of L_s apart). In all cases, a uniform horizontal grid of 7½° of latitude by 9° of longitude was used and 13 vertical levels spanning an altitude range of 47 km was employed.

These simulations have a number of implications for the polar regions: First, the atmosphere becomes cold enough in the winter polar region for carbon dioxide to condense in the atmosphere as well as at the surface. In the inner portion of the seasonal cap region, several tens of percent of the total condensation takes place in the atmosphere. This implies that carbon dioxide clouds should be ubiquitous in the winter polar regions, in accord with IRTM data. As such clouds act as scatterers rather than absorbers of thermal radiation, they will reduce the amount of thermal radiation emitted to space in the winter polar regions and hence lead to a reduced rate of carbon dioxide condensation. Condensation of carbon dioxide in the atmosphere is expected to take place on dust and water ice particles and thus acts to cleanse the winter polar atmosphere of these aerosols and to incorporate them into the seasonal polar caps.

Atmospheric heat transport into the polar regions is an important (but not dominant) component of the energy budget of the winter polar regions. There are significant seasonal variations in both the total atmospheric heat transport into these regions and its division between the zonally averaged circulation and eddy circulation (especially baroclinic modes).

PERPETUAL WINTER SIMULATIONS OF THE MARTIAN ATMOSPHERIC CIRCULATION USING A 3D GLOBAL SPECTRAL MODEL: IMPLICATIONS FOR THE POLEWARD TRANSPORT OF WATER.

Robert M. Haberle (NASA/Ames), H. Houben (Mycol, Inc.), and Richard E. Young (NASA/Ames)

During sprintime in the northern hemisphere of Mars the seasonal CO2 polar cap retreats poleward. By the end of spring it completely sublimes and exposes an underlying deposit of water ice. Viking measurements have shown that this residual north polar ice cap acts as source for atmospheric water (1,2). Modeling studies suggest that while the north residual cap does supply a significant fraction of the observed increase in northern hemisphere water vapor during summer, it cannot be the only source (3). The studies also indicate that not all of the water supplied to the atmosphere by the cap is returned at the end of summer. If the water lost by the residual cap during summer is not replenished at other times of year then on an annual basis, the north residual cap is losing water.

The annual mass budget of the north residual cap is an uncertain but crucial issue for understanding the nature of the Martian climate - past and present. If, for example, the cap is experiencing a net loss of water then the reservoirs to which this water is migrating must be identified. One possibility is that the water lost by the north residual cap is ultimately incorporated into the south residual cap (4). Such a net transfer of water may play an important role in the formation of the layered terrains that characterize both polar regions (5), and could also be involved in interannual variations of the water cycle itself (6). On the other hand, the relatively high albedo of the north residual cap has been interpreted in terms of a stable polar cap mass balance (7), Indeed, the residual cap could even be gaining water on an annual basis. Thus, even the sign the cap's annual mass budget is uncertain.

One approach toward resolution of this issue is to construct realistic models of the atmospheric circulation and apply them to polar transport problems. Several such models have been constructed (3,8). In this paper we report the results of preliminary calculations using a 3D global spectral model designed to assess the abiltiy of the wintertime circulation to transport water poleward. We focus on winter because at this season the circulation of midlatitudes is characterized by traveling baroclinic storm systems (eddies) which can be very effective agents for the poleward transport water.

Our approach is to simulate steady-state conditions for northern winter during non-dust storm periods. In order to focus on the dynamics we greatly simplify the model's physical representations (heating, friction,

ect.) and run at high vertical and horizontal resolution. We then diagnose the model's output in terms of key dynamical quantities that are indicative of the potential for transport (such as EP-Fluxes and "residual circulations"). Among the results we find thus far are: (1) The simulated eddies provide only a modest enhancement in poleward transport. Most of the enhancement occurs at low levels poleward of 60N. (2) A predominance in the simulations of eddy activity at low zonal wavenumbers (1 and 2). In all our simulations, surprisingly strong westerly jets occur which we believe limit the growth of the higher wavenumber eddies through barotropic processes. While probably unrealistic, this result does have implications for the behavior of waves during global dust sotrms. (3) A weak sensitivity to the values of the sruface drag, at least over the range of damping times examined (1 to 10 days).

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ON THE TRANSPORT OF DUST AND WATER TO NORTHERN HIGH LATITUDES IN MARTIAN DUST STORMS; Jeffrey R. Barnes, Department of Atmospheric Sciences, Oregon State University, Corvallis, OR 97331

It has been suggested that substantial transports of dust and water to northern polar latitudes take place during global dust storms, and that these transports may play a very important role in the current climate system of Mars. In the case of the water cycle, such transports could represent a "return" of water that is sublimed and transported away from the north residual polar cap during summer (1). In the case of dust, such transports could act to preferentially "dirty" the (seasonal and residual) north polar cap, a key factor in the non-existence of a CO_2 residual cap in the north (2). The deposition of dust may be substantially enhanced by condensation scavenging - a process for which the simultaneous transport of water is important (3). Dust deposition at very high latitudes in the north may be a crucial part of processes leading to the formation of the polar layered terrains (3, 4).

A key issue, clearly, is whether substantial transports of dust and water to northern polar latitudes really do occur during global dust storms (or at any other times). Presently available observations certainly do not permit this issue to be resolved (at least not directly; they do provide some indirect constraints), though future ones - those to be obtained by Mars Observer, in particular - may. In the meantime, numerical simulations may be able to provide considerable insight. This paper examines some of the results of such simulations, especially those from a recently completed study (5).

Numerical simulations performed with a zonally symmetric model have shown that dust can be rapidly transported to low and middle latitudes of the northern hemisphere from a source region in the southern subtropics (6). In these simulations virtually no dust reaches north polar latitudes. There are fundamental dynamical reasons underlying this lack of polar transport, the same ones that underly the absence of polar atmospheric warming in these simulations (5, 6, 7). The observation of intense polar warming (8), during at least some global dust storms, indicates that strong (and very anomalous) dynamical activity is taking place at high northern latitudes: activity that results in the transport of heat, and also, almost certainly, various atmospheric trace constituents including dust and water (5, 7). Numerical studies with a relatively simplified model have shown that forced planetary waves could be the

primary source for this anomalous high-latitude dynamical activity - in much the same way that they are in the case of sudden stratospheric warmings in the Earth's atmosphere (7). It has long been known that these polar warmings are accompanied by substantial poleward transports of trace substances.

To examine the dust and water transports that might take place during a Martian polar warming/dust storm event numerical simulations have been performed utilizing a simplified transport model (5). These transport simulations are strictly passive in nature, so that radiative-dynamical feedbacks are ignored in the case of dust. The latter may be a reasonable approximation for processes in the winter polar atmosphere. Some of the dust simulations incorporate sedimentation and vertical mixing, allowing a simple representation of surface deposition. In the water transport simulations, condensation and precipitation are not allowed to occur (this may not be a bad approximation, in view of the very high temperatures that prevail throughout the polar atmosphere during a warming event). In some of the water and dust simulations a source is present in order to crudely model transport into the northern middle and high latitude domain.

The results of these simulations generally confirm the anticipation that substantial quantities of dust and water could be transported to northern high latitudes (extending to the pole) in a polar warming/dust storm event. If forced planetary waves indeed play a key dynamical role, then the poleward transports are associated primarily with strong (quasi-horizontal) dispersive mixing, and are not very sensitive to the "initial" (present in the very early stages of a global dust storm) distributions of dust and water. If planetary wave mixing is not present and the transport is predominantly advective in character (as it would be, for example, if breaking gravity waves are crucially involved in the warming dynamics), then the poleward transport is fairly sensitive to the initial distribution. In this case, large poleward transports are produced if large amounts of dust and water are initially present at relatively high levels (above ~ 10-15 km) in low and middle latitudes. Actual transport magnitudes in the simulations are dependent upon the initial quantities of dust and water in low and middle latitudes, and upon the extent to which this initial loading is "resupplied" during an event. For plausible initial states and source strengths, the simulations yield deposited layers of dust ~ 1-20 μm thick in polar latitudes, and total water transports (northward across 60° latitude) of the order of 1×10^{11} kg or larger. Dust and water transports of these magnitudes would certainly be quite significant, in the ways mentioned above.

The simplicity (simplified geometry, dynamics, and physics) of the models employed in these dust and water transport studies is considerable, and demands that the results be regarded as merely illustrative of processes that may actually be occurring in the Martian atmosphere. Further work with more realistic models will be required for a quantitative assessment of the importance of northern high-latitude dust and water transports in global dust storms. Such an assessment may be very difficult, in view of the complexity and "special" (highly anomalous and transient) character of a dust storm/polar warming event. [A quantitative assessment of the role (in middle atmosphere climate) of transports during terrestrial sudden stratospheric warmings cannot be made at present.] Related problems that clearly also have to be addressed include the nature of high-latitude dust and water transports during non-dust storm periods: both "normal" wintertime periods and summer (including spring and fall) periods.

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NUMERICAL MODELING OF PLANETARY WAVE-MEAN FLOW INTERACTION IN THE MARS ATMOSPHERE: APPLICATIONS TO THE POLAR WARMING PHENOMENON; J. L. Hollingsworth and J. R. Barnes, Department of Atmospheric Sciences, Oregon State University, Corvallis, OR 97331.

Viking IRTM observations (at 15 microns) show that shortly after the outbreak of the 1977 winter solstice global dust storm on Mars, an intense atmospheric polar warming took place (1,2). In particular, at north polar latitudes temperatures near the 25 km level increased by 40-70 K during a period of less than three weeks. Since direct solar heating associated with increased atmospheric dustiness could not have produced the high temperatures observed within the polar night, the warming must have been the result of dynamical processes. Recent dynamical modeling with a simplified quasi-geostrophic model demonstrates that these processes may have involved forced planetary waves. Such a dynamical mechanism appears to be capable of producing a polar warming having the magnitude and suddenness of that observed, given sufficiently large wave forcing (3).

The greatest limitation of the quasi-geostrophic study is that the model used does not allow meridional wave propagation (only vertical propagation) nor changes in the meridional structure of the zonal-mean flow due to interactions with the wave. These processes are known to be important for the planetary wave-mean flow interactions that occur during terrestrial sudden stratospheric warmings. We are pursuing an extension of the previous modeling efforts that employs a more realistic dynamical model. Incorporating spherical geometry, this model represents the interaction of a single zonal wave component with the zonal-mean flow, allowing the dynamical processes referred to above (4). The model also relaxes some of the approximations of quasi-geostrophy. Simplified physics are contained in the model: diabatic heating is represented as Newtonian cooling and frictional drag is included in the form of a height-dependent Rayleigh friction.

In preparation for nonlinear wave-mean flow numerical experiments, we have performed some calculations using this model in a 'linear' form (suppressing the wave flux terms in the zonal-mean equations). An analytic representation of the zonal-mean winter thermal structure as contructed from Mariner 9 IRIS data (5), has been employed as a basic state; the corresponding gradient balance wind field is shown in Fig. 1a. A useful diagnostic quantity, based on linear theory, that indicates how conducive a particular zonal-mean state is to vertical and meridional wave propagation is Matsuno's refractive index (6). Planetary waves should tend to propagate into regions of positive index and avoid regions of negative index. For the winter basic state, a channel of positive index values extends from the surface upward into the jet core in midlatitudes (Fig. 1b); negative values are found on both the poleward and equatorward sides of the jet. For an initial linear experiment, a zonal wavenumber 1 forcing corresponding to a 100 m height perturbation centered at 60 deg N was specified. Fig. 1c shows the equilibrated wave structure. It can be seen that the wave has

propagated well up into the jet core, which would appear to be consistent with the refractive index distribution.

Future calculations will be made to investigate the response of various (e.g., dust storm and non-dust storm) zonal-mean basic states to planetary wave forcings, both topographic and thermal. In particular, the dependence on the strength and meridional structure of the wave forcing will be examined, for several zonal wavenumbers. Nonlinear experiments, where zonal-mean fields are allowed to change in response to an upward and meridionally propagating planetary wave -- thereby altering the wave's propagation -- will be conducted.

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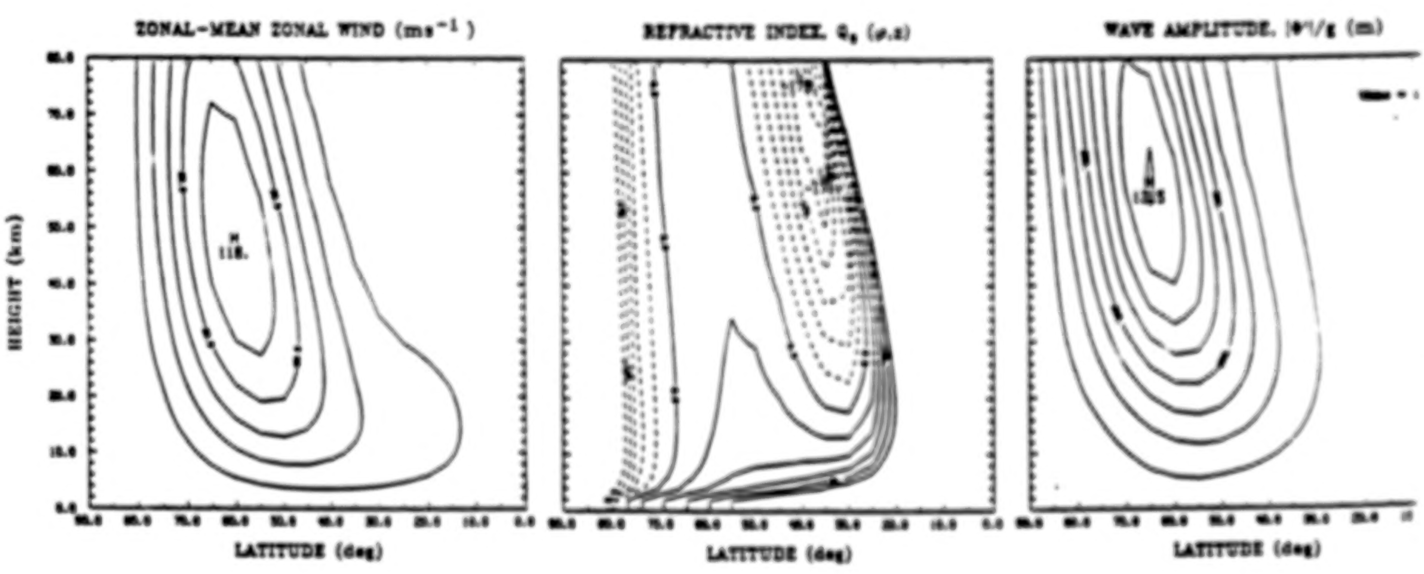

(a) (b) (c)

Fig. 1. Latitude-height structure of various fields for the linear calculations: (a) zonal-mean zonal wind speed (ms^{-1}), the contour interval is 20 ms^{-1}; (b) refractive index pattern for zonal wavenumber 1 (non-dimensional), negative values dashed with a contour interval of 30; (c) steady-state wave geopotential amplitude structure (m), the contour interval is 150 m.

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DUST PARTICLE FALLOUT DURING GLOBAL DUST STORMS: 1-D SIMULATIONS

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Two dimensional modelling studies of the transport of dust in the martian atmosphere have been ineffective at transporting dust into high northern latitudes during global dust storm simulations(1). We are preparing to couple an aerosol model (2) with the Mars GCM in an attempt to more accurately simulate the atmospheric circulation and dust transport during a global dust storm. Before proceeding with 3-D investigations, we wish to first determine if we can more clearly define some of the processes governing dust particle lifetimes with a 1-D version of the aerosol model.

Martian global dust storm decay phases have been observed by Mariner 9 (1971) and the Viking landers and orbiters (1977a,1977b). The IRIS data from Mariner 9 provided information about the dust particle composition, and size and vertical distributions (3). These data also indicated that the upper and lower portions of the atmosphere cleared at the same rate (4), and that the particle size distribution did not appreciably change during the observation time of @ 100 sols (3). These latter two observations indicate that gravitational settling alone was not controlling the rate of dust removal from the atmosphere, with diffusion of 10**7 cm2/s (4) and particle coagulation (5) being suggested as the reasons for each of these observations, respectively.

The visible optical depth values provided by the Viking lander imaging experiment, in conjunction with the dust particle properties inferred from the Mariner 9 IRIS data, give us the opportunity to investigate the importance of the previously mentioned physical processes as they relate to the observed decay of a global dust storm. We have performed 1-D simulations with the aerosol model in an attempt to match the observed optical depths from the Viking

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landers (primarily lander 1). We attempt this match by the inclusion or exclusion, in the aerosol model, of the various physical processes which play a part in determining particle lifetimes. The aerosol model treats vertical advection allowing for non-uniform spacing of grid points. Atmospheric density and aerosol concentration are assumed to vary exponentially between vertical grid points. Particle concentrations and fall velocities are carried at layer midpoints, while atmospheric vertical velocities are carried at layer bounds. The advantages of this scheme are that advection is treated accurately even when sharp gradients occur, diffusion is treated accurately, and advective-diffusive equilibrium is treated without error. The scheme does, however, produce a 5-10% phase error in peak positions during vertical advection.

We choose as our initial condition size distribution #1 from (3), constant mass mixing ratio with height, and consider the dust to have the physical properties of montmorillonite 219b (3). The atmosphere is assumed isothermal at 220 K.

The 1977a storm had a peak optical depth at lander 1 of @ 3.2, which decreased exponentially with a time constant of 75 sols for 70 sols, and more slowly thereafter (6). Treating the dust particles as spheres and allowing them to simply gravitationally settle resulted in a much too rapid decline in optical depth. Inclusion of diffusion (10**7 cm2/s) slowed the optical depth decline, but not nearly enough to match the observations. Increased diffusion and vertical variation of the diffusion had negligible additional effect. The addition of Brownian coagulation resulted in a slightly more rapid decrease in optical depth and did little to offset the greater loss of large particles relative to small particles. The fact that the

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simulations were insensitive to diffusion coefficients greater than 10**7 indicates that the surface depostion rates are controlling the particle lifetimes. The inclusion of a particle photophoretic velocity at the surface can have substantial impact upon deposition rates, and we are in the process of examining whether the thermal gradient between the martian atmosphere and surface is sufficient for this to be a significant process.

Another possible way to reduce the surface deposition rate is to reduce the particle fall velocities. This can be accomplished by treating the particles as discs rather than spheres. Disc shaped particles with a ratio of thickness to diameter (ESHAPE) of 0.1 have fall speeds which in the presence of reasonable diffusion produce optical depth declines very near to those observed at lander 1. Such plate-like shapes are not inconsistent with those expected for clay particles, and also agree with particle shape results from lander 1 imaging (6).

In none of our model simulations have we been able to match the observation of the absence of particle size distribution change with time. Since the IRIS observations were made at 20 degrees South near the dust source region they may reflect geographic variations in the vertical wind velocities.

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SESSION III: POLAR GEOLOGY

QUANTITATIVE PROPERTIES OF THE SOUTH POLAR LAYERED DEPOSITS ON MARS; K. E. Herkenhoff, S. S. C. Wu[1], L. A. Soderblom[1] and B. C. Murray, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125 and [1]U. S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001

The Martian polar layered deposits record global climatic variations over the last 10^7 to 10^8 years through cyclic deposition/erosion of dust and ice (Carr, 1982). Some detailed investigations of the north polar deposits have been published (Blasius *et al.*, 1982; Howard *et al.*, 1982), but the analysis of the south polar layered deposits has not been extended much beyond the Mariner 9 mission results (Murray *et al.*, 1972; Cutts, 1973). This neglect is due, in part, to the fact that the highest resolution images of the south polar region were recorded by the Mariner 9 television system. Improved quantitative results may now be derived from these picture data (Herkenhoff et al., 1988). Also, recent progress in modeling of dust scattering in the Martian atmosphere by Herkenhoff and Murray (1988) allows approximate removal of the component of brightness due to atmospheric scattering in images of Mars. Such removal is essential to the accurate evaluation of Martian surface albedo and photometric properties, and has been performed on both Mariner 9 and Viking Orbiter images. We are now quantitatively analyzing 60-100 m/pixel resolution Mariner 9 images of the south polar layered deposits.

Initial results to be presented at the workshop include:

1. Stereophotogrammetric modeling using Mariner 9 B (narrow angle) frames is underway in order to determine the surface slopes of layer outcrops, the attitudes of individual layers, and local relief. Such information will yield the thicknesses of individual layers and help resolve the ambiguity between albedo variations and topographic modulation of surface brightness.

2. New south polar Viking three-color mosaics offer the opportunity to detect any color variations within the layered terrains and to compare the color of the layered deposits with that of surrounding terrains. Intensities in each of the violet, green and red mosaics will be corrected for atmospheric scattering and normalized to those in the clear mosaic to diminish topographic and photometric effects. Implications of this study for the composition of the layered deposits will be discussed.

3. Photoclinometric techniques are being applied to Mariner 9 south polar layered terrain images. Intrinsic albedo differences can be separated from topographic effects. Variations in albedo along layers and contrasts between layers will be presented, along with discussion of possible explanations of the results.

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Accumulation of sedimentary debris in th esouth polar region of Mars, and implications for climate history*, **J. Plaut, R. Kahn, E. Guinness, and R. Arvidson, McDonnell Center for the Space Sciences, Department of Earth and Planetary Sciences, Washington University, St. Louis, MO**

Stratigraphic units of the south polar region of Mars were mapped. relative chronology determined. and detailed modeling of the observed crater populations was used to set absolute constraints on the age of emplacement of materials. Significant secular variation in the net debris accumulation rate over history is evident. An episode of enhanced crater obliteration at about 3.7 Ga ago. lasting a few hundred Ma. is inferred for south polar cratered terrains. A similar peak in low latitude obliteration rates suggests that the event may have been global in scale. Whether the debris is volcanic or aeolian in origin, the event suggests a possible enhancement in atmospheric density at the time. Modeling results imply that cratered terrains poleward of 65° south latitude have subsequently experienced steady state net accumulation of material at a rate of about 0.1 km/Ga. while equatorial cratered terrains have been retained in relatively pristine form. Fifteen craters of impact origin were discovered on the south polar layered terrain. formerly thought to be almost devoid of craters. Their presence implies that the surface is at least a few 100 Ma old. and that the net accumulation rate is no more than 10 km/Ga. If layer formation is modulated by periodic climatic effects. either the period of oscillation is a few Ma or longer. or the layer deposition mechanism ceased operating at least several 100 Ma ago.

***Paper to be presented by R. Kahn**

MARS: DUNE SAND SOURCES IN NORTH POLAR LAYERED DEPOSITS
P. C. Thomas, Cornell University

The occurrence of sand dunes on Mars is primarily concentrated in three latitudinal zones: the north polar erg, large intracrater dune fields surrounding the south polar deposits, and low latitude crater and canyon dune fields. Howard (1) noted that some dunes within the area of northern layered deposits were associated with steep arcuate scarps and might be erosional products from the layers. Thomas (2) and Saunders (3,4) also found the relationship important, and supportive of sources of dune materials within the polar deposits.

This study used morphologic and color mapping to investigate the relationship of the dunes to the layered polar deposits (P.L.D.).

The usual views of the polar layered deposits as dust/ice carried to the poles in suspension have caused considerable reluctance to accept the P.L.D. as sources of sand-sized material moved by saltation. For this study we have mapped the occurrence of dunes in the P.L.D., their morphologic associations, and their colors. Important relations found include:

1. The arcuate, steep (5-20°) scarps are associated with most dune occurrences within the area of P.L.D. (Figs. 1, 2).
2. The scarps and associated dunes have restricted occurrences in two linear zones in the P.L.D.
3. The dune and other wind-directed features indicate movement away from the scarps (Fig. 1).
4. The dune/scarp occurrences are near the edges or in large reentrants of the P.L.D., and are often in areas of complex trough patterns (crossing, curving; Fig. 1).
5. The P.L.D. contain material that is similar in color (red/violet = 3) and albedo to the red dust seen elsewhere on Mars and carried in suspension in dust storms (Fig. 3).
6. The P.L.D. colors also indicate some areas have darker, less red material, mixed below the resolution limit of 50 m/pixel.
7. The polar dunes are basically the same colors as dark dunes elsewhere on Mars (Fig. 3).

From these observations it can be concluded that the material making up the polar dunes is essentially the same as materials forming dunes at all other latitudes, and that they are in some manner interbedded with the dust/ice of the P.L.D. This material is currently being eroded from the P.L.D. The similarity to other dark dunes on Mars suggests exotic polar processes are not necessary to produce this saltating material.

Supported by NASA grant NAGW-111.

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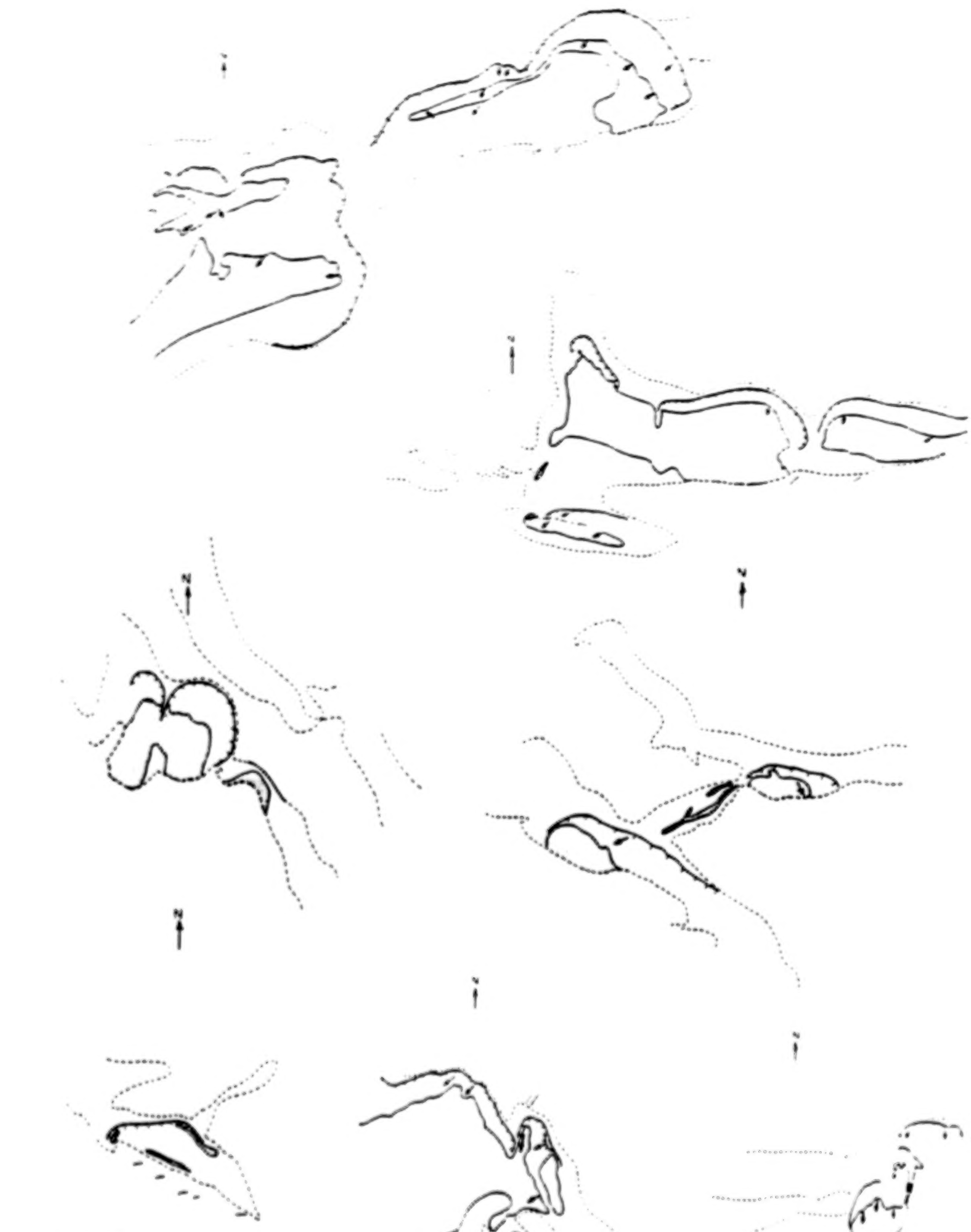

Fig. 1. Examples of the association of polar dunes and steep, arcuate scarps in P.L.D. Stippled areas are dunes, dashed lines mark trough margins, and scarps are hachured lines. Wind directions from barchan orientations, framing dunes, and wind streaks indicate flow out from the scarps.

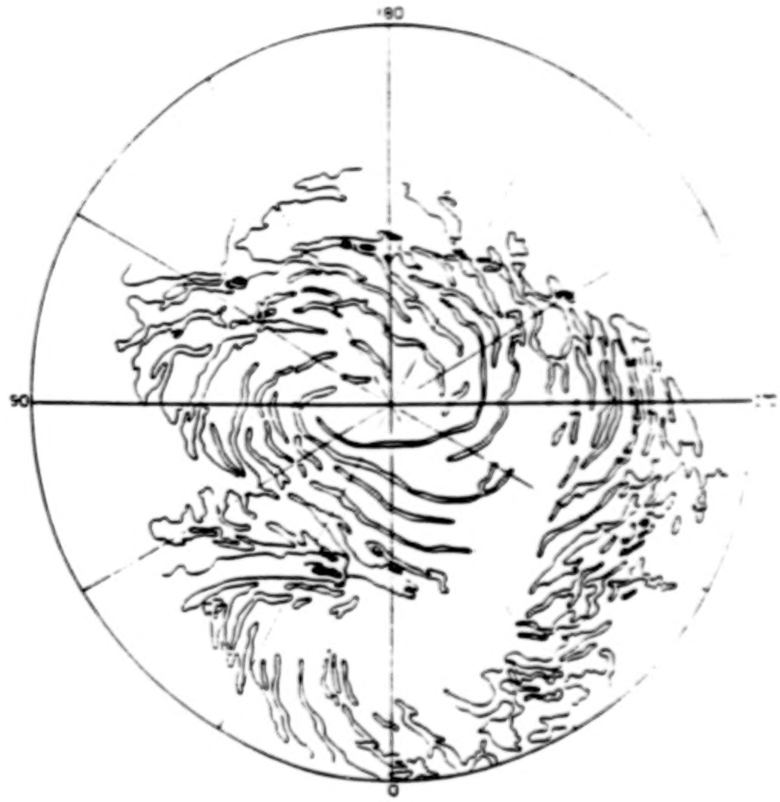

Fig. 2. Location of dune sources in P.L.D. Dark areas mark dunes near scarps. The restricted occurrence suggests structural control, as do trough outlines. The dune occurrence in the outer and lower parts of the P.L.D. suggest sands are in older parts of the P.L.D.

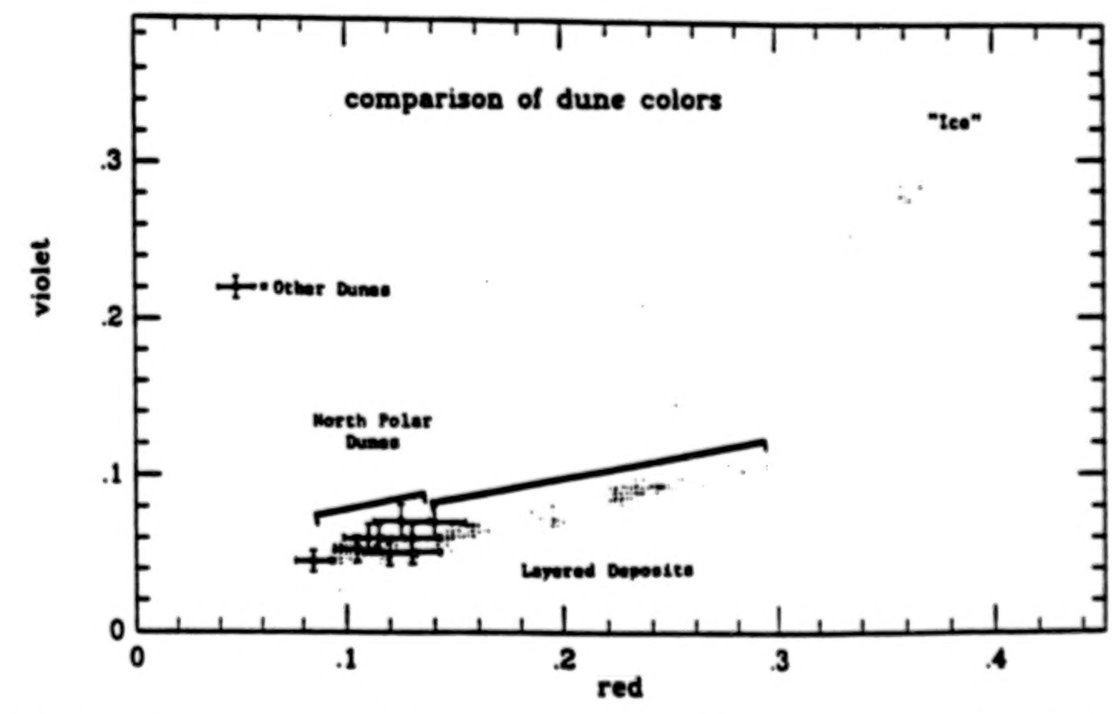

Fig. 3. Colors of polar layered deposits dunes and "ice" at - 83°N, 240°W. Data from VO images with scattering function used to compare data from different areas. P.L.D. contain bright, red "dust," and some darker material. Dune colors from several locations at lower latitudes are compared, and are similar to polar dunes (R/V - 2.0).

MARS: NORTH POLAR DUNES: POSSIBLE FORMATION FROM LOW-DENSITY POLAR SUBLIMATE RESIDUES.

R. Saunders[1], Alex Storrs[2], David Blewett[3], Fraser Fanale[4], and James Stephens[1]

Low density aggregates, composed of submicron clay aerosols, have been formed experimentally as the sublimation residues of masses of dust-nucleated ice [R. S. Saunders. F. P. Fanale, T. J. Parker, J. B. Stephens, and S. Sutton, Icarus, 66, 94 (1986); "The Formation of Filamentary Sublimate Residues from mineral grains", Storrs, Fanale, Saunders, and Stephens (Icarus, in press); R. Saunders and D. Blewett, Astron Vestnik, V.21, p.181-188, 1987.] These ice-dust mixtures are possible analogues of materials of Martian north polar deposits. Low density (.002 g/cm^3) spheroidal pellets formed from these materials in vacuum chamber experiments have been examined as possible candidates for forming north polar dunes on Mars. It is shown that these particles move like sand grains under conditions of saltation and, given a sufficient supply, would be capable of forming the dunes observed in the north circumpolar erg.

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BASAL MELTING AND THE MARTIAN POLAR MASS BALANCE. Stephen M. Clifford, Lunar and Planetary Institute, 3303 NASA Rd 1, Houston, TX, 77546.

It is generally accepted that the martian polar deposits owe their origin and apparent youthfulness to the annual deposition of dust and H_2O, and that the magnitude of this deposition has been modulated by periodic variations in insolation due to changes in the martian orbital elements and obliquity [1, 2, 3]. On the basis of their evident thickness and the absence of any craters with diameters larger than 300 m, it is estimated that the deposits accumulated on a time scale of $\sim 10^8$ years [2, 4]. However, recent studies suggest that climatic conditions conducive to polar deposition are not unique to the present epoch but have existed throughout most of martian geologic history [5, 6]. Given such conditions, and the apparent youthfulness of the present deposits, how does one account for the lack of any older material at the poles?

One possibility is that periods of intense polar erosion have alternated with climatic periods of accumulation [7]. Such erosion must be extremely efficient in redistributing the resulting debris if it is to eliminate any previous record of polar construction. However, no significant variable in the martian climate with a period greater than the $\sim 10^6$-year variation in orbital eccentricity has yet been identified [8, 9]. Further, the periodic changes in insolation that result from the interaction of such time-varying astronomical parameters appears to fall well short of that required to counter the net long-term deposition of ice and dust at the poles [5, 6]. This conclusion is supported by both the inferred 10^7-10^8 year age of the present deposits and by the lack of observational evidence indicative of any widespread erosion of the polar laminae [10].

Another possible solution to the mass balance problem is that new polar laminae are simply created at the expense of the old [3]. This suggestion is based on current models of the evolution of the polar troughs [10, 11]. These features, which appear to spiral out from the centers of the remnant caps, are thought to originate near the edge of the deposits and migrate toward the pole. This migration is thought to be driven by the preferential sublimation of ice from the equatorward facing slopes of the troughs. Dust, liberated from the polar ice, may then be scavenged by polar winds and redistributed over the planet, while the sublimed ice may simply be recycled by cold trapping on the poleward facing slopes and on the flats that separate the polar troughs. By these processes, the polar deposits may have reached a state of equilibrium whereby ancient ($\sim 10^9$ year old) polar material is continually reworked, maintaining a comparatively youthful surficial appearance in spite of its great age [3].

However, based on a detailed study of polar stratigraphy made from high-resolution Viking Orbiter imagery, Howard et al. [10] have argued that a simple local recycling of polar laminae is untenable. They support this conclusion by citing observational evidence that the erosion of equatorward facing scarps has not kept pace with layer deposition near the poles, requiring a net long-term accumulation of material within the polar terrains.

To summarize, it appears that any solution to the mass balance problem must (i) be consistent with theoretical models of the martian climate, which indicate that a net deposition environment has existed at the poles throughout most of the planet's geologic history [5,6], (ii) be able to account for the observational evidence that the evolution of the polar terrains has indeed been dominated by deposition processes [10], (iii) be able to accommodate a rate of deposition, implied by the lack of craters within the deposits, of at least 10^{-4} m yr^{-1} [2,4], and (iv) satisfy all of the previous conditions within the constraint imposed by the apparent deficit of material that currently exists at the poles.

A fundamental assumption in most mass balance studies of the martian polar caps is that mass loss can only occur from the cap's exposed surface. By this reasoning, the volume of material stored in the caps is a cumulative record of the net imbalance that has existed between polar deposition and erosion throughout martian climatic history. However, as discussed by Clifford [12], these assumptions are violated if the thickness of the deposits becomes large enough for geothermal melting to occur at the base.

Recent estimates of the total inventory of H_2O on Mars [13,14] are sufficiently large ($\geq 10^7$ km^3) that, at least near the poles, ice may be present throughout the cryosphere (Figure

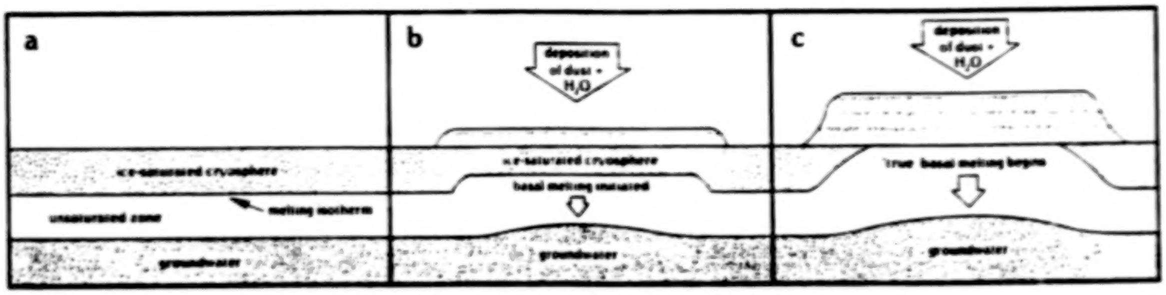

Fig. 1. An idealized cross section of the polar crust illustrating the possible time evolution of basal melting. The sequence depicts (a) a time prior to the deposition of any dust and ice, (b) the onset of deposition and basal melting, and (c) melting at the actual base of the deposits.

1a). If so, the deposition and retention of any material at the surface will result in a situation where the equilibrium depth to the melting isotherm has been exceeded, melting ice at the base of the cryosphere until thermodynamic equilibrium is once again established (Figure 1b). Should deposition persist, the polar deposits will ultimately reach a thickness where melting will occur at their actual base (Figure 1c). At this point the cap will reach a state of equilibrium, where the deposition of any additional ice is balanced by geothermal melting.

Basal melting thicknesses, calculated from a reasonable range of thermal conductivities and salt-induced melting temperatures, are summarized in Table 1 and Figure 2. The calculations are based on a mean polar surface temperature of 157 K and a geothermal heat flux of 3×10^{-2} W m^{-2} [12]. The results are consistent with the inferred 4-6 km thickness of the present north polar cap [15]; however, in the south, the deposits appear sufficiently thin (1-2 km) that geothermal melting is likely to be relegated to a depth that lies well below the regolith-polar cap interface (e.g., Figure 1b). (Note that if basal sliding occurs, the resulting frictional heat could substantially reduce the thickness required for basal melting. For example, the heat generated by a sliding velocity of 10 m yr^{-1}, driven by a basal shear stress of 100 kPa, will halve the values presented in Table 1).

Should the polar deposits reach the required thickness for basal melting, a geothermal heat flux of 3×10^{-2} W m^{-2} K^{-1} will melt sufficient ice to keep pace with an H_2O deposition rate as high as 5×10^{-3} m per martian year. The resulting meltwater will then drain and fill the available pore space that exists beneath the cryosphere. Thus, basal melting successfully resolves the apparent conflict between the modest volume of the current polar deposits and the long-term existence of a net depositional environment at the poles [5, 6, 10].

Of course, while basal melting may resolve the eventual fate of the polar ice, there still remains the problem of the polar dust. Fortunately, the dust mass balance is significantly more tractable, in that the nonvolatile nature of the dust allows it to be physically removed from the polar troughs by surficial processes of erosion and redistributed to nonpolar latitudes. Alternatively, the possibility of glacial flow suggests that any basal debris may eventually be transported to the periphery of the cap, where it may be scoured away by strong seasonal winds.

Because the martian polar terrains will yield important clues about the planet's climatic history, they are certain to be high-priority objectives of any future exploration. While a variety of techniques are likely to be employed in these investigations, two (active seismic exploration and radio echo sounding) appear particularly promising because of their ability to probe the physical properties, internal structure, and basal topography of the deposits over large areas and to great depths [16, 17, 18, 19]. Since both methods have been successfully applied to the detection of basal melting on earth [20, 21], the use of either technique should provide a credible test of whether basal melting has occurred on Mars.

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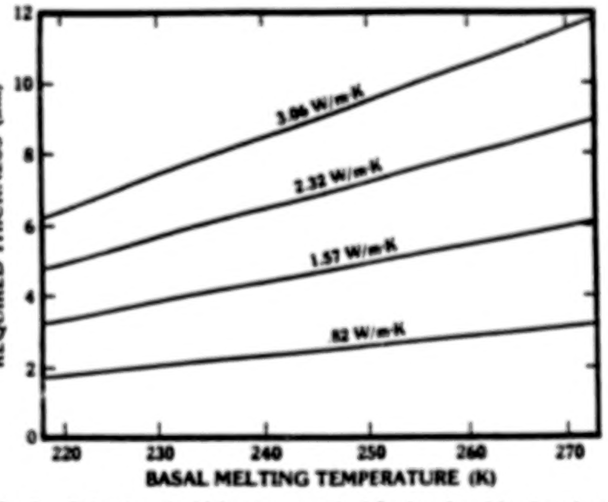

Fig. 2. Polar deposit thicknesses required for basal melting based on a mean annual surface temperature of 157 K, a geothermal heat flux of 3×10^{-2} W m^{-2}, and thermal conductivities covering the range from 0.82 to 3.06 W m^{-1} K^{-1}.

TABLE 1. Calculated Basal Melting Thicknesses

Polar Deposit Thermal Conductivity, W m^{-1} K^{-1}	Basal Melting Temperatures		
	218 K	252 K	273 K
0.82	1.67	2.60	3.17
1.57	3.19	4.97	6.07
2.32	4.72	7.35	8.97
3.06	6.22	9.69	11.8

Thicknesses are in kilometers.

These results are based on a mean polar surface temperature of 157 K and geothermal heat flux of 3×10^{-2} W m^{-2}.

SESSION IV: FUTURE MEASUREMENTS

POLYOXYMETHYLENE AT THE POLAR CAPS OF MARS? D. C. Boice and W. F. Huebner, Southwest Research Institute, San Antonio, TX 78284

Polymerized formaldehyde or polyoxymethylene (POM) has been identified from ion mass spectra obtained with the Positive Ion Cluster Composition Analyser (PICCA) on the Giotto spacecraft in the coma of comet P/Halley (1-3). Data from the Neutral Mass Spectrometer lends additional support to this identification and data from several other spacecraft instruments are consistent with the properties of POM (4). Laboratory experiments on frozen gases exposed to ultraviolet (uv) radiation or MeV-type charged particles indicate that comets may acquire a mantle of less volatile H-C-O-N compounds from exposure to cosmic radiation for $4.5 \cdot 10^9$ years in the Oort cloud. However, during the many passages that the comet has made through the inner solar system, this surface layer has been eroded away by the solar heating of the frozen gases. The POM that is observed comes from the present surface layer which could not have formed POM during one orbital period (76 years). Therefore, POM is present throughout the nucleus which means that it must have existed before the comet was formed.

Based on low temperature laboratory work (5-7), Huebner et al. (8) proposed a scenario in which POM formed on grains in an interstellar cloud environment with condensed H_2O and CO, and exposed to cosmic radiation. The key in this process is the conversion of CO to CO_2 through disproportionation upon condensation. Preliminary laboratory experiments indicate that disproportionation occurs, but its efficiency must still be determined. After a frozen mixture of water and carbon dioxide has been formed on grains, the cosmic radiation (simulated in the laboratory by MeV-type helium ions) induces a reaction that leads to the formation of formaldehyde (5). Under continued exposure to cosmic radiation (simulated in the laboratory by radiation form ^{60}Co and bremsstrahlung from MeV-type electrons) the formaldehyde polymerizes exothermically at temperatures as low as 170 K down to 4 K (6, 7).

The major requirements for the formation of POM on the polar caps of Mars exist: Abundance of H_2O and CO_2 ice, low temperature, and exposure to cosmic or uv radiation because of the lack of a substantial atmosphere. The least well known process in our above scenario, the disproportionation of CO, is not required. Whether POM occurs on Mars is not known and depends on the proportion of H_2O to CO_2 in the ice, how well the water and carbon dioxide ices are mixed, how long the permafrost layers survive over climatic time scales, and the influence that dust grains in the icy mixture may have on the reactions to form formaldehyde in the frozen state and solid POM. It is interesting to note that this is not the first time that formation of POM has been suggested on the planets. The existence of POM glycols in the atmosphere of Venus had been suggested and, subsequently, withdrawn by Wildt (9). If POM

should form at all, the temperature on Venus is too high for it to survive. POM unzippers to form formaldehyde monomer at a temperature of about 440 K. In the gas phase, formaldehyde is quickly destroyed by solar uv radiation. Because temperatures never reach 440 K on Mars, any POM that forms in the solid phase would be stable.

An additional property of POM is its affinity to attach to silicate and possibly metal oxide surfaces; it forms whiskers on silicate dust grains. Since all of the ingredients to form POM or POM glycols exist at the polar caps of Mars, we would expect to find at least stable traces of it in the surface layer. However, we expect little or no evidence for POM in the atmosphere. The vapor pressure of POM is lower than that of water. The POM vapor will quickly photodissociate or unzipper to form H_2CO which, in turn, photodissociates rapidly in the Martian atmosphere under the influence of solar uv. For this reason it is not surprising that formaldehyde or POM was not detected by the Viking spacecraft at mid-latitudes.

To detect POM on Mars, a properly instrumented balloon that flies over the polar cap region and periodically touches down to analyze the permafrost is one possible approach. Instruments that would aid in the identification of POM must complement one another. These might include (1) a custom mass spectrometer that could slowly heat a sample, measure the spectrum of liberated volatiles to high molecular mass (~200 amu), and impact aggregate clusters for elemental analysis; (2) an SEM for studying larger structures such as whiskers and flakes on grain surfaces; (3) an IR spectrometer to search for spectral features consistent with POM; and (4) a gas chromatograph or other appropriate instruments to perform chemical analysis. Since cosmic radiation can produce POM below the surface (in contrast to uv radiation) and to counter seasonal Martian snow, methods and instruments to sample below the surface may also be desirable.

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MARTIAN POLAR CAP ANALYTICAL SYSTEM: OBJECTIVES AND DESIGN

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There has long been uncertainty about the cause of ice ages on earth. Although almost everybody agrees that orbital parameters have a major influen on the global climate, most argue that this effect alone cannot account for t Pleistocene glaciations. One group holds the view that the primary cause is be found in endogenic processes that affect the atmosphere of the planet and alter the global albedo. Another group has argued that the ice ages are caus by fluctuations in the solar irradiance. Clearly, if we could obtain a climatic record from Mars and compare it with the climatic record from the earth it should be possible to determine which factor plays the major role in planetary climate change. In view of the anticipated climatic change that ma scientists predict for the earth, this objective would appear to be a significant goal. We have been able to obtain long-term records of solar activity and climate from the polar ice sheet of Antarctica and we believe th similar data could be recovered from the polar ice caps of Mars.

There are a number of types of information that could be obtained from a detailed analysis of the polar ice caps of Mars and the purpose of this repor is to outline both the potential significance of the analyses and the general design of the apparatus needed to accomplish these objectives. Many analytic measurements can be accomplished by on-site analytical systems which avoid th complexities and expense of sample return missions. While admittedly, core return to earth would provide a high yield of information, it would be extremely costly and it is doubtful that it could be justified until a suite on-site studies had been completed. Furthermore, our experience in Antarctic with on-site analysis of polar ice samples indicates that contamination problems are greatly reduced. We have found that high resolution analysis of ice cores from Antarctica provides a record of both past solar activity variations and past climatic changes. An example of a nitrate record obtaine from Antarctica is shown in Figure 1. More detailed records will be provided to show the capacity of high-resolution analysis to resolve minor changes in solar activity.

We recommend the use of a Philberth probe which would melt its way into the polar cap and provide continuous physical and chemical analyses as it descended. The probe would be launched from the lander and would be provided with an internal heat source. It would be stabilized by a pendulum system so that it would descend on a nearly vertical path. The probe would carry on board systems for determination of ice density, suspended particle count and grain size. In addition, apparatus would be provided that would perform chemical analysis on the melt stream flowing around the heated probe. This apparatus would be capable of determining carbon dioxide, pH, nitrate ion concentration, and an assortment of other anions and cations that can be measured by ion selective electrode techniques. Automatic calibration would be incorporated into all flow channels in the continuous flow analytical

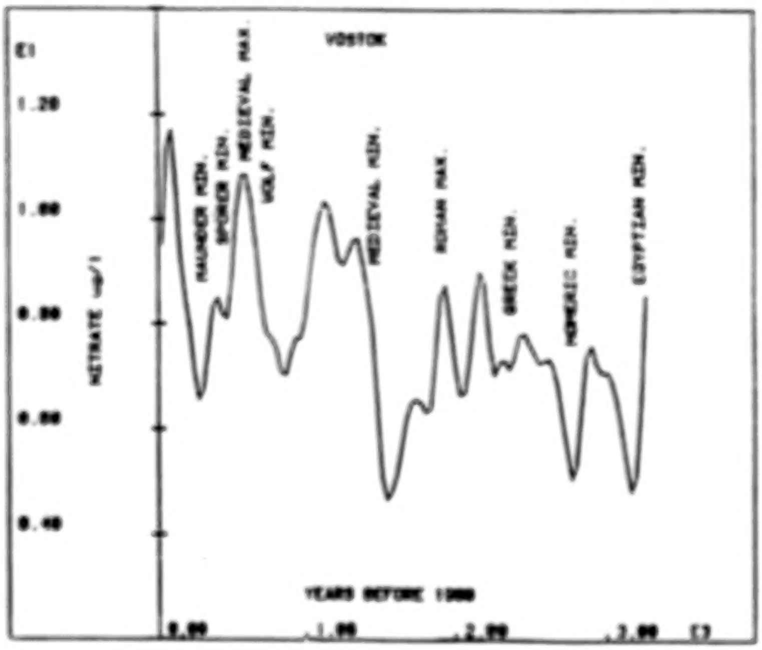

Figure 1. Smoothed curve of NO_3^- concentrations for the past 3000 years from Vostok firn core, Antarctica.

system and data would be transmitted by wire to the surface where it would be forewarded by the uplink of the lander to the orbiter for transmission to earth. All systems would be designed to provide micro-resolution analytical data through the entire vertical path of the probe system. The data obtained would be especially useful in design of any future ice core return missions.

ABSTRACT

Field Use of a Composite Coring Auger in Polar Regions

This paper will discuss use of a composite hand auger in cold regions. Extrapolations to a martian environment are considered.

Bit geometries, core breaking force and power requirements will also be described. A sample bit and short version of the core barrel will be available for discussion purposes.

INVESTIGATION OF THE MARTIAN POLAR REGIONS VIA GAMMA-RAY SPECTROSCOPY.

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The upcoming Mars Observer mission will include in its payload a gamma-ray spectrometer that will measure the energy spectrum of gamma radiation emitted by the planet, as well as information about the energy distribution and flux of leakage neutrons. From these data it will be possible to infer a considerable amount of surface composition information. In particular, the experiment is very well suited to investigation of the polar regions, due to (a) its high sensitivity to H_2O and CO_2, and (b) the nature of the spacecraft orbit, which leads to the longest integration times and hence highest quality data near the poles.

The presence of H_2O can be investigated directly by measurement of the 2.223 MeV gamma-ray line of H. Because H is the most important element for moderating the neutrons produced by cosmic-ray interactions with the surface, it can also be investigated by the direct or indirect determination of the fast to thermal ratio of the neutron leakage flux. The neutron fast/thermal ratio may be determined indirectly from the gamma-ray spectrum. Prompt capture lines result primarily from interactions of nuclei with thermal neutrons, while inelastic scattering lines result primarily from interactions with fast neutrons. Some elements, such as Si and Fe, emit strong lines of both types. One may therefore examine ratios of inelastic scatter to prompt capture line strengths for these elements, and acquire information regarding the H distribution. The 2.223 MeV flux is an indicator of the amount of H in the upper few tens of g/cm^2, while the inelastic/capture ratio for Si or Fe is related to the amount of H in the upper 100 g/cm^2 or more. It is therefore possible to obtain information about the vertical distribution of H. CO_2 is more difficult to detect by this method, but it may be possible to determine the thickness of a layer of CO_2 frost by direct detection of C or by inference from attenuation of gamma rays from underlying material.

H and C, because they are effective neutron moderators, also will produce substantial perturbations to the leakage neutron spectra. These perturbations will be determined directly by the experiment's neutron mode, providing an independent measure of H_2O and CO_2 concentrations and vertical distributions.

We wish to determine how effectively questions regarding the distribution of H_2O and CO_2 in the martian polar regions may be addressed with Mars Observer GRS data. For example (1) What is the ice/dust ratio of the polar layered deposits? (2) What is the thickness of the polar perennial ice? (3) What is the thickness of the CO_2 that covers the southern perennial ice? (4) What is the thickness of the seasonal CO_2 frost cap? (5) How much H_2O is there in the seasonal frost cap? We perform calculations that incorporate a realistic primary cosmic-ray spectrum, the resultant secondary neutron source distribution, neutron scattering and moderation in layered materials, gamma-ray production by prompt capture and inelastic scatter reactions (as well as by natural radionuclides), gamma-ray attenuation and continuum background production, detector efficiency, and integration time as a function of latitude. We will present these calculations and use them to show how the Mars Observer GRS data can be used to address these questions.

A Strategy for the Climatological Science Objectives of the Mars Observer Mission

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Winds are crucial for determining the poleward transports of volatiles, heat, and dust and for exploring the circulation of the atmosphere. Yet the Mars Observer (MO) spacecraft has no instrument that will directly measure winds. Dynamical models therefore provide a necessary link between the winds and measurable quantities such as temperature, clouds, and water vapor.

There are two kinds of models and many sources of uncertainty. Balanced models use a restrictive set of assumptions to derive an approximate wind field directly from the observed variables. Examples include the geostrophic circulation assuming no wind at the surface, the residual mean circulation driven by radiative heating, and solar thermal tides. Time–marching models derive future values of all variables (winds, temperatures, pressures, volatiles, and dust) from present initial conditions. The initial conditions come either from the model itself or from observations. In the former case, observations are used only to validate the climatology of the model; the best model is presumably the one whose seasonal means, variances, covariances, etc., are closest to observed values. In the latter case, observations are used continuously to update the model; the best model is the one that stays closest to the real atmosphere as it evolves in time.

Several tests are possible before MO is launched. The restrictive assumptions of the balanced models may be tested against a less restrictive general circulation model (GCM). The GCM generates a synthetic MO data set spanning one Martian seasonal cycle. The balanced model uses the data to estimate winds, from which transports of volatiles, heat, and dust are computed. The success of the balanced model in reproducing the winds and transports of the original GCM is noted. A weakness of this test is that the GCM may be inaccurate; for instance, it may be more or less geostrophic than the real atmosphere.

Time–marching models may be used before launch to see which climatological variables of the MO data set are most diagnostic. One could generate synthetic MO data sets for a variety of GCM's, each with its own treatment of turbulence, clouds, dust, radiation, and other sub–grid processes. The question is, in a blind test, could the different models be identified from the climatologies of their synthetic data sets alone? Even if the answer is yes, the method is only useful if one or more of the GCM climatologies eventually matches that of the real MO data within acceptable limits.

The other test of the time–marching models is to see which of them is most successful in following the other models when continuously updated with synthetic MO data from those other models. Presumably that model would also be most successful in following the Mars atmosphere when that model is updated with real MO data. The advantage of continuous updating, if successful, is that one then has a continuous picture of the Mars atmospheric circulation as it evolves. The disadvantage is that model validation uses more computer time than a validation based on climatology alone (computer time goes as the square of the number of models rather than the number itself).

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16. Abstract

Included in this publication is a collection of abstracts from the NASA-sponsored workshop "Polar Processes on Mars," which was held at the Sunnyvale Hilton Hotel, Sunnyvale, California, on May 12 and 13, 1988. Support for the workshop came from NASA's Planetary Geology and Geophysics program managed by Dr. Joseph Boyce. The workshop is one of a series of workshops identified by MECA (MECA is an acronym for Mars: Evolution of its Climate and Atmosphere) as being worthy of focused research, but one for which it was not possible to hold during the project's lifetime. Consequently, it was held after the project ended. The MECA project was part of the Mars Data Analysis program.

The workshop consisted of four sessions: The Polar Caps, Dynamics/Atmospheric Processes, Polar Geology, and Future Measurements. To put things into perspective, each of the first three sessions began with a review. All sessions were scheduled to allow ample time for discussion., A brief review of each section is provided.

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